

CEMENTED CARBIDE INSERT

BACKGROUND OF THE INVENTION

The present invention relates to a coated cutting tool insert particularly useful for turning of steel, like low alloyed steels, carbon steels and tough
5 hardened steels, at high cutting speeds.

High performance cutting tools must nowadays possess high wear resistance, high toughness properties and good resistance to plastic deformation. This is particularly so when the cutting operation is carried out at very high cutting speeds and/or at high feed rates when large amount of heat is generated.

10 Improved resistance to plastic deformation of a cutting insert can be obtained by decreasing the WC grain size and/or by lowering the overall binder phase content, but such changes will simultaneously result in significant loss in the toughness of the insert.

Methods to improve the toughness behaviour by introducing a thick
15 essentially cubic carbide free and binder phase enriched surface zone with a thickness of about 20-40 μm on the inserts by so called gradient sintering techniques are in the art.

However, these methods produce a rather hard cutting edge due to a depletion of binder phase and enrichment of cubic phases along the cutting edge.
20 A hard cutting edge is more prone to chipping. Nevertheless, such carbide inserts

with essentially cubic carbide free and binder phase enriched surface zones are extensively used today for machining steel and stainless steel.

There are ways to overcome the problem with edge brittleness by controlling the carbide composition along the cutting edge by employing special sintering techniques or by using certain alloying elements, of which US 5,484,468, US 5,549,980, US 5,729,823 and US 5,643,658 are illustrated.

All these techniques give a binder phase enrichment in the outermost region of the edge. However, inserts produced according to these techniques often obtain micro plastic deformation at the outermost part of the cutting edge. In particular, this often occurs when the machining is carried out at high cutting speeds. A micro plastic deformation of the cutting edge will cause a rapid flank wear and hence a shortened lifetime of the cutting inserts. A further drawback of the above-mentioned techniques is that they are complex and difficult to fully control.

US 5,786,069 and US 5,863,640 disclose coated cutting tool inserts with a binder phase enriched surface zone and a highly W-alloyed binder phase.

SUMMARY

The present invention provides a cutting tool insert for machining steel, including a cemented carbide body and a coating, wherein: the cemented carbide body includes WC, 2-10 wt. % of Co, 4-12 wt. % of cubic carbides of metals from groups 4, 5 or 6 of the periodic table, and N in an amount of between 0.9 and 1.7 % of the weight of the elements from groups 4 and 5; the cemented carbide body

includes a Co-binder phase which is highly alloyed with W, and has a CW-ratio of 0.75-0.90; the cemented carbide body has a surface zone with a thickness of $< 20 \mu\text{m}$, which is binder phase enriched and essentially cubic carbide free; the cemented carbide body has a cutting edge which has a binder phase content which is 0.65-0.75 of the bulk binder phase content, and the binder phase content increases at a constant rate along a line which bisects said cutting edge, until it reaches the bulk binder phase content at a distance between 100 and 300 μm from the cutting edge; and the coating includes a 3-12 μm columnar TiCN layer followed by a 2-12 μm Al_2O_3 layer, possibly with an outermost 0.5-4 μm TiN layer.

The present invention also provides a method of making a cutting insert comprising a cemented carbide body having a binder phase, with a binder phase enriched surface zone and a binder phase depleted cutting edge, and a coating, including the steps of: forming a powder mixture including WC, 2-10 wt. % Co, 4-12 wt. % of cubic carbides of metals from groups 4, 5 or 6 of the periodic table, the binder phase having a CW-ratio of 0.75-0.90; adding N in an amount of between 0.9 and 1.7% of the weight of the elements from groups 4 and 5; mixing the powder with a pressing agent; milling and spray drying the mixture to a powder material compacting and sintering the powder material at a temperature of 1300-1500°C, in a controlled atmosphere of sintering gas at 40-60 mbar followed by cooling; applying post-sintering treatment; and applying a hard, wear resistant coating by CVD or MT-CVD-technique.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic drawing of a cross section of an edge of an insert gradient sintered according to the present invention.

5 DETAILED DESCRIPTION OF THE EMBODIMENTS

It has now surprisingly been found that significant improvements with respect to resistance to plastic deformation and toughness behaviour can simultaneously be obtained for a cemented carbide insert if a number of features are combined. The improvement in cutting performance of the cemented carbide
10 inserts can be obtained if the cobalt binder phase is highly alloyed with W, if the essentially cubic carbide free and binder phase enriched surface zone A has a certain thickness and composition, if the cubic carbide composition near the cutting edge B is optimised and if the insert is coated with a 3-12 μm columnar TiCN-layer followed by a 2-12 μm thick Al_2O_3 layer, for example produced
15 according to any of the patents US 5,766,782, US 5,654,035, US 5,674,564 or US 5,702,808, possibly with an outermost 0.5 - 4 μm TiN-layer. The Al_2O_3 -layer will serve as an effective thermal barrier during cutting and thereby improve not only the resistance to plastic deformation which is a heat influenced property but also increase the crater wear resistance of the cemented carbide insert. In
20 addition, if the coating along the cutting edge is smoothed by an appropriate technique, like by brushing with a SiC-based nylon brush or by a gentle blasting

with Al_2O_3 grains, the cutting performance can be enhanced further, in particular with respect to flaking resistance of the coating (see, e.g. US 5,851,210).

Said cutting insert possesses excellent cutting performance when machining steel at high cutting-speeds, in particular low alloyed steels, carbon steels and tough hardened steels. As a result a wider application area for the coated carbide insert is obtained because the cemented carbide insert according to the invention performs very well at both low and very high cutting speeds under both continuous and intermittent cutting conditions.

The coated cemented carbide insert of the invention has a $< 20 \mu\text{m}$, preferably $5-15 \mu\text{m}$, thick essentially cubic carbide free and binder phase enriched surface zone A (Fig. 1), preferably with an average binder phase content (by volume) of 1.2-3.0 times the bulk binder phase content. In order to obtain high resistance to plastic deformation but simultaneously avoid a brittle cutting edge the chemical composition is optimised in zone B (Fig. 1). Along line C (Fig. 1), in the direction from edge to the centre of the insert, the binder phase content increases essentially constantly until it reaches the bulk composition. At the edge the binder phase content by volume is 0.65-0.75, preferably about 0.7 times the binder phase content of the bulk. In a similar way, the cubic carbide phase content decreases along line C, preferably from about 1.3 times the content of the bulk. The depth of the binder phase depletion and cubic carbide enrichment along line C is $100-300 \mu\text{m}$, preferably $150-250 \mu\text{m}$.

The binder phase is highly W-alloyed. The content of W in the binder phase can be expressed as a

CW-ratio = $M_s / (\text{wt. \% Co} * 0.0161)$ where M_s is the measured saturation magnetisation of the cemented carbide body in kA/m and wt-% Co is the weight percentage of Co in the cemented carbide. The CW-ratio takes a value ≤ 1 and the lower the CW-ratio, the higher is the W-content in the binder phase. It has now been found according to the invention that an improved cutting performance is achieved if the CW-ratio is 0.75-0.90, preferably 0.80-0.85.

Inserts according to the invention are further provided with a coating consisting of essentially 3-12 μm columnar TiCN-layer followed by a 2-12 μm thick Al_2O_3 -layer deposited, for example according to any of the patents US 5,766,782, US 5,654,035, US 5,674,564, US 5,702,808 preferably with an α - Al_2O_3 -layer, possibly with an outermost 0.5-4 μm TiN-layer.

The present invention is applicable to cemented carbides with a composition of 2-10, preferably 4-7, weight percent of binder phase consisting of Co, and 4-12, preferably 7-10, weight percent cubic carbides of the metals from groups 4, 5 or 6 of the periodic table, preferably > 1 wt. % of each Ti, Ta and Nb and a balance WC. The WC preferably has an average grain size of 1.0 to 4.0 μm , more preferably 2.0 to 3.0 μm . The cemented carbide body may contain small amounts, < 1 volume %, of η -phase (M_6C).

By applying layers with different thicknesses on the cemented carbide body according to the invention, the property of the coated insert can be optimised to

suit specific cutting conditions. In one embodiment, a cemented carbide insert produced according to the invention is provided with a coating of: 6 μm TiCN, 8 μm Al_2O_3 and 2 μm TiN. This coated insert is particularly suited for cutting operation with high demand regarding crater wear. In another embodiment, a
5 cemented carbide insert produced according to invention is provided with a coating of: 8 μm TiCN, 4 μm Al_2O_3 and 2 μm TiN. This coating is particularly suited for cutting operations with high demands on flank wear resistance.

The invention also relates to a method of making cutting inserts comprising a cemented carbide substrate consisting of a binder phase of Co, WC and a cubic
10 carbonitride phase with a binder phase enriched surface zone essentially free of cubic phase and a coating. The powder mixture consists 2-10, preferably 4-7, weight percent of binder phase consisting of Co, and 4-12, preferably 7-10, weight percent cubic carbides of the metals from groups 4, 5 or 6 of the periodic table, preferably > 1 wt. % of each Ti, Ta and Nb and a balance WC, preferably
15 with an average grain size of 1.0-4.0 μm , more preferably 2.0-3.0 μm . Well-controlled amounts of nitrogen are added either through the powder as carbonitrides and/or added during the sintering process via the sintering gas atmosphere. The amount of added nitrogen will determine the rate of dissolution of the cubic phases during the sintering process and hence determine the overall
20 distribution of the elements in the cemented carbide after solidification. The optimum amount of nitrogen to be added depends on the composition of the cemented carbide and in particular on the amount of cubic phases and varies

between 0.9 and 1.7%, preferably about 1.1-1.4%, of the weight of the elements from groups 4 and 5 of the periodic table. The exact conditions depend to a certain extent on the design of the sintering equipment being used. It is within the purview of the skilled artisan to determine whether the requisite surface zones A and B of cemented carbide have been obtained and to modify the nitrogen addition and the sintering process in accordance with the present specification in order to obtain the desired result.

The raw materials are mixed with pressing agent and possibly W such that the desired CW-ratio of the binder phase is obtained and the mixture is milled and spray dried to obtain a powder material with the desired properties. Next, the powder material is compacted and sintered. Sintering is performed at a temperature of 1300-1500°C, in a controlled atmosphere of between 40 and 60 mbar, preferably about 50 mbar, followed by cooling. After conventional post sintering treatments including edge rounding a hard, wear resistant coating, such as defined above, is applied by CVD- or MT-CVD-technique.

Example 1

A.) Cemented carbide turning inserts of the style CNMG120408-PM, DNMG150612-PM and CNMG160616-PR, with the composition 5.5 wt. % Co, 3.5 wt. % TaC, 2.3 wt. % NbC, 2.1 wt. % TiC and 0.4 wt. % TiN and balance WC with an average grain size of 2.5 μm were produced according to the invention. The nitrogen was added to the carbide powder as TiCN. Sintering was done at

1450°C in a controlled atmosphere consisting of Ar, CO and some N₂ at a total pressure of about 50 mbar.

Metallographic investigation showed that the produced cemented carbide inserts had a cubic-carbide-free zone A with a thickness of 10 μm. Image analysis technique was used to determine the phase composition at zone B and the area along line C (Fig. 1). The measurements were done on polished cross sections of the inserts over an area of approx. 40 x 40 μm gradually moving along the line C. The phase composition was determined as volume fractions. The analysis showed that the cobalt content in zone B was 0.7 times the bulk cobalt content and the cubic carbide content 1.3 times the bulk gamma phase content. The measurements of the bulk content were also done by image analysis technique. The Co-content was gradually increasing and the cubic carbide content gradually decreasing along line C in the direction from the edge to the centre of the insert.

Magnetic saturation values were recorded and used for calculating CW-values. An average CW-value of 0.84 was obtained.

B.) Inserts from A were first coated with a thin layer < 1 μm of TiN followed by 6 μm thick layer of TiCN with columnar grains by using MT-CVD-techniques (process temperature 850°C and CH₃CN as the carbon/nitrogen source). In a subsequent process step during the same coating cycle, an 8 μm thick α-Al₂O₃ layer was deposited according to patent US 5,654,035. On top of the α-Al₂O₃ layer a 1.5 μm TiN layer was deposited.

C.) Inserts from A were first coated by a thin layer $< 1 \mu\text{m}$ of TiN followed by a $9 \mu\text{m}$ thick TiCN-layer and a $5 \mu\text{m}$ thick $\alpha\text{-Al}_2\text{O}_3$ layer and a $2 \mu\text{m}$ thick TiN layer on top. The same coating procedures as given in A.) were used.

D.) Commercially available cutting insert in style CNMG120408-PM,
5 DNMG150612-PM and CNMG160616-PR, with the composition given below were used as references in the cutting tests:

Composition: Co = 5.5 wt. %, TaC = 5.5 wt. %, NbC = 2.3 wt. %, TiC = 2.6 wt. % and balance WC with a grain size $2.6 \mu\text{m}$. Cobalt enriched gradient zone: none

10 CW-ratio: > 0.95

Coating: $8 \mu\text{m}$ TiCN, $6 \mu\text{m}$ Al_2O_3 , $0.5 \mu\text{m}$ TiN on top

E.) Inserts with the same cemented carbide composition as in D were coated with $4 \mu\text{m}$ TiN and $6 \mu\text{m}$ Al_2O_3 . Inserts styles CNMG120408-QM and CNMG120412-MR.

15 F.) Inserts in styles CNMG120408-QM and CNMG120412-MR with the composition: 4.7 wt. % Co, 3.1 wt. % TaC, 2.0 wt. % NbC, 3.4 wt. %, TiC 0.2 wt. % N and rest WC with a grain size of $2.5 \mu\text{m}$ were produced. The inserts were sintered according to the method described in patent US 5,484,468, i.e., a method that gives cobalt enrichment in zone B. The sintered carbide inserts had a
20 $25 \mu\text{m}$ thick gradient zone essentially free from cubic carbide. The inserts were coated with the same coating as in E.

Example 2

Inserts from B and C of Example 1 were tested and compared with inserts from D with respect to toughness in a longitudinal. turning operation with interrupted cuts.

5 Material: Carbon steel SS1312.

Cutting data:

Cutting speed = 140 m/min

Depth of cut = 2.0 mm

Feed = Starting with 0.12 mm and gradually increased by 0.08

10 mm/min until breakage of the edge

15 edges of each variant were tested

Inserts style: CNMG120408-PM

Results:

mean feed at breakage

15 Inserts B 0.23 mm/rev

Inserts C 0.23 mm/rev

Inserts D 0.18 mm/rev

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Example 3

Inserts from B, C and D of Example 1 were tested with respect to resistance to plastic deformation in longitudinal turning of alloyed steel (AISI 4340).

5 Cutting data:

Cutting speed = 160 m/min
Feed = 0.7 mm/rev.
Depth of cut = 2 mm
Time in cut = 0.50 min

10 The plastic deformation was measured as the edge depression at the nose of the inserts.

Results:	Edge depression, μm
Insert B	43
Insert C	44
Insert D	75

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Examples 2 and 3 show that the inserts B and C according to the invention exhibit much better plastic deformation resistance in combination with somewhat better toughness behaviour in comparison to the inserts D according to prior art.

Example 4

Inserts from E and F of Example 1 were tested with respect to flank wear resistance in longitudinal turning of ball bearing steel SKF25B.

Cutting data:

5 Cutting speed: 320 m/min
 Feed: 0.3 mm/rev.
 Depth of cut: 2 mm

Tool life criteria: Flank wear > 0.3 mm

Results:

10 Tool life
Insert E 8 min
Insert F 6 min

Variant F exhibited micro plastic deformation resulting in more rapid development of the flank wear.

15 Example 5

Inserts from E and F of Example 1 in inserts style CNMG120412-MR were tested at an end-user in machining of a steel casting component.

Cutting data:

Cutting speed: 170-180 m/min

Feed: 0.18 mm/rev.

Depth of cut: 3 mm

The component had the shape of a ring. The inserts machined two components each and the total time in cut was 13.2 min.

5 After the test the flank wear of the inserts were measured.

Results:

	Flank wear
Insert E	0.32 mm
Insert F	0.60 mm

10 Example 4 and 5 illustrate the detrimental effect of cobalt enrichment in the edge area B typical for inserts produced by prior art gradient sintering technique as described in e.g. US 5,484,468.

Example 6

15 Inserts from B and D from Example 1 were tested under the same condition as in Example 4. Inserts style CNMG120408-PM

Cutting data:

Cutting speed: 320 m/min

Feed: 0.3 mm/rev.

Depth of cut: 2 mm

Tool life criteria: Flank wear > 0.3 mm

Results: Tool life

Insert B	8 min
Insert D	8 min

5 Example 7

Inserts from B and D of Example 1 were tested at an end user in the machining of cardan shafts in tough hardened steel. Insert style DNMG150612-PM.

Cutting condition:

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Cutting speed:	150 m/min
Feed:	0.3 mm/rev.
Depth of cut:	3 mm

The inserts machined 50 component each. Afterwards the flank wear of the inserts was measured.

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Results:

	Flank wear
Insert B	0.15 mm
Insert D	0.30 mm

Examples 6 and 7 illustrate that inserts with an optimised edge zone composition according to the invention do not suffer from micro plastic deformation and hence no rapid flank wear as prior art gradient sintered insert F does (see examples 4 and 5).

5 Example 8

In a test performed at an end-user inserts from B, C and D in Example 1 in style CNMG160616-PR were run in a longitudinal turning operation in machining of crankshaft in low alloyed steel.

10 The inserts were allowed to machine 90 crankshafts and the flank wear was measured and compared.

 Cutting data:

Cutting speed:	220 m/min
Feed:	0.6 mm/rev.
Depth of cut:	3-5 mm
15 Total time in cut:	27 min.

The dominating wear mechanism was plastic deformation of the type edge impression causing a flank wear.

 Results:

20 Flank wear

Insert B	0.2 mm
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Insert D 0.6 mm

5 D.

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